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The Optoelectronic Research Center at the University of New Mexico has continued to develop its research capabilities during this reporting period. With partial support from the Air Force Office of Scientific Research, a comprehensive set of facilities for opto-electronics research including materials growth, fabrication science, device development and integration have been established. Allied efforts in laser spectroscopy, in theory and modelling and in manufacturing science provide a uniquely complete environment for important developments in optoelectronics. Specific accomplishments during this period include: development of advanced metal-organic chemical vapor deposition growth of III-V semiconductors: PLZT films for non-linear optical applications: sub-um grating fabrication investigations: development of photolithographic and etching and switching properties of high-power diode lasers. A substantial effort has been devoted to the development of resonant-periodic gain, surface-emitting lasers.

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Submitted to:
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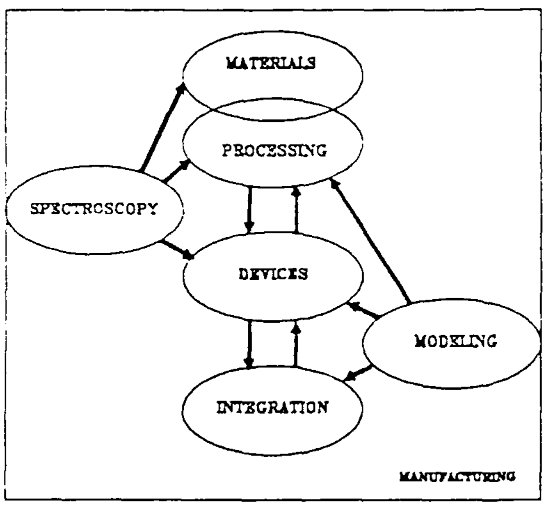
Very substantial effort has been devoted to the development of an outstanding Optoelectronics Research program at the Center for High Technology Materials. The resources provided by the Air Force Office of Scientific Research Optoelectronics Research Center program have played a major role in this process.

The figure gives a capsule outline of the structure of this research program. The vertical integration that includes strong, and well coupled, efforts in materials growth, fabrication and processing, device development and optoelectronic integration is a major cornerstone of our success. All of these links are essential for the development of optoelectronic components and systems. Complementary efforts in spectroscopy for the evaluation of all phases of this program and in modeling and analysis provide important insights. An overall awareness of manufacturing constraints and requirements, typified by our large SEMATECH program, provides a further unique aspect to this program that increases its relevance and importance to industry. This tight coupling has not been a traditional strength of the American University system with its emphasis on individual investigators and strong disciplinary boundaries. CHTM's interdisciplinary charter and strong organization has allowed us to develop a unique structure that is recognized as increasingly important for the large-scale interdisciplinary research necessary for today's challenges.



CHTM vertically-structured research program

Laboratories

State-of-the-art laboratories are an essential requirement for advanced research in optoelectronics and microelectronics. The CHTM laboratories, funded by the state funds, by the AFOSR program, and by additional external contracts, provide a major resource. An abbreviated list of these laboratories is included to provide some background of the development of CHTM.

Materials Growth:

Crystal Growth Facility
(South Campus)
Advanced metal-organic chemical vapor deposition (MOCVD) reactor for the epitaxial growth of III-V semiconductors; related sample preparation and diagnostic equipment.

Liquid-Phase Epitaxy
(EECE building)
located in class-100 cleanroom (see below)

Nonlinear-Optical Thin Films
(EECE building)
rf-sputter system, multi-target dc-sputter system, ceramic target preparation, sol-gel deposition, optical characterization

Ion-Assisted Thin-Film Deposition
(EECE building)
ion-assisted, ion-beam deposition reactors (3) for thin films, spectrophotometers, sample preparation, high repetition rate excimer laser and system for laser-ablation deposition of thin-films

Fabrication and Processing:

Class-100 Cleanroom
(EECE building)
2,000 ft^2 high quality class-100 cleanroom with eight bays
sub-micron lithography, low pressure CVD for oxides and nitrides, LPE, plasma and reactive ion beam etch systems, characterization, thermal diffusion furnaces, rapid thermal anneal, uv-photoresist strippers, alloy st[illegible]s, wet chemistry
this is a well equipped facility which provides a superior capability for the fabrication of advanced semiconductor devices.

Plasma Etching
(EECE building)
plasma and reactive-ion etch systems, optical diagnostics

Pulsed Magnetron Etching
(EECE building)
high-power pulsed microwave etching system for semiconductors

Ion-beam optical figuring
(EECE building)
ion-beam optical figuring of large (30 cm) optics; interferometer, vacuum chambers, computer control

Additional Facilities
(EECE building)
scanning electron microscope, polishing, mounting bonding capabilities, e-beam metallization system

Device Development and Optoelectronic Integration:

Diode Laser Physics
(EECE building)
spectroscopic instrumentation, high-speed electronics, external cavity diode lasers

Laser Arrays and Characterization
(EECE building)
shearing interferometer, diode laser probe test, near-field and far-field patterns, spectroscopic and high speed instrumentation

Optoelectronics
(EECE building)
electrochemical profiler, parameter analyzer, analysis instrumentation, C-V, I-V analysis

High-Speed Detectors
(EECE building)
uv-heterodyne interferometer for evaluation of very high-speed detectors, rf-instrumentation including spectrum and network analyzers

Spectroscopy:

Laser-Material Interactions
(EECE building)
Ar-ion laser, frequency doubler, cw-dye laser, Q-switched YAG/dye laser, cw-modelocked YAG/dye laser, Raman spectrometer, high-speed digital oscilloscopes, sampling oscilloscope

Ultrafast Spectroscopy
(Physics building)
ultrafast colliding-pulse modelocked dye lasers (3); ultrafast laser amplifiers, ultrafast analysis capabilities, ring-laser gyroscope, streak camera

Nonlinear Optics
(Physics building)
high-power YAG oscillator-amplifier, spectroscopic instrumentation

Nanoscale Microanalysis
(Physics building)
field-ion microscope, time-of-flight mass analysis, imaging-atom probe

Manufacturing:

Scatterometry
(EECE building)
scatterometers for application to semiconductor manufacturing, Ar-ion laser, extensive computational capability

Chemometrics and FT-IR
(Chemistry building)
Fourier Transform Infrared Spectrometer, instrumentation for both transmission and emission spectroscopy, extensive computational capability

Plasma Analysis and Characterization
(Ferris Engineering Center)
plasma deposition and etching systems, analytical instrumentation

STM/Confocal Microscopy
(Chemistry building)
scanning tunneling microscope, STM tip fabrication facilities, confocal polarization microscopes (2)

Materials Growth

Materials growth research efforts at CHTM include III-V semiconductors grown by Liquid Phase Epitaxy (LPE) and Metal Organic Crystal Vapor Deposition (MOCVD), ion-assisted thin film deposition, nonlinear optical thin films (PLZT, $BaTiO_3$) and high T_c superconducting films. The MOCVD reactor is housed at the Crystal Growth Facility, completed early in 1988, on the UNM South Campus. The facility and associated safety system are model installations. The center's class-100 cleanroom also houses facilities for LPE growth. Highlights are discussed below.

MOCVD Crystal Growth:

We have continued to advance the state-of-the-art in semiconductor optoelectronic materials. Collaborations and contracts have been established and are on-going with the Army Night Vision and Electro-optics Laboratory, David Sarnoff Research Center (previously RCA research laboratories), Spectra Diode Laboratories, McDonnell Douglas Astronautics Corporation, University of California at Los Angeles and at Berkeley, and, as previously, with Sandia National Laboratories and the Air Force Weapons Laboratory.

A major portion of effort has been dedicated to semiconductor laser diode growth and fabrication. Structures grown by MOCVD and fabricated at CHTM have demonstrated superior performance with overall wall-plug power conversion efficiencies as high as 60%. With these GaAs/AlGaAs structures we have fabricated laser diodes operating from 725 to 870 nm. The use of strained GaInAs materials in combination with our excellent GaAs/AlGaAs materials has allowed us to pioneer laser diodes at wavelengths from 850 to 1000 nm with even better performance and reductions in threshold current density of over 30%. In fact, a recent result obtained in collaboration with Spectra Diode Labs has demonstrated lasing at 960 nm with over 3 Watts of cw power at room temperature from a 100-μm gain-guided phased array diode.

Remarkable results have been obtained in terms of the reproducibility of our MOCVD growth process. The thickness and composition of the epitaxial layers have been demonstrated to be stable to within ± 1.0% over several weeks. This has allowed us to grow laser diode structures for a variety of solid-state laser pumping applications. These include 808-nm diodes for Nd:YAG, 785-nm diodes for Tm, Ho:YAG and strained diode lasers at 970 nm for Er:glass and Er:YAG eye-safe laser range-finders.

These highly uniform, efficient diode pumps are presently being used by the Army Night Vision Laboratories for development of future weapons and defense systems.

In addition to the laser diode materials, we have continued to pursue several other electron device structures both at CHTM and also in collaboration with UCLA. These include pseudomorphic GaInAs/AlGaAs HEMT's, superlattice IMPATT diodes, bipolar heterojunction transistors and hot electron (theta) transistors. We have also grown materials for quantum well, long-wavelength photodetectors based on free electron absorption and graded composition AlGaAs MSM high-speed UV-photodiodes for an MIT Lincoln Labs contract. These devices have all exhibited state-of-the-art performance.

The most recent, and perhaps most exciting, research in materials growth has centered on the vertical cavity surface-emitting lasers. We have for the first time, proposed and demonstrated the concept of resonant periodic gain vertical cavity lasers grown by MOCVD. These devices have exhibited over 45% optical power conversion efficiency, cw, at room temperature when optically pumped. This has created much excitement in the laser community and will soon be applied to injection pumped devices for applications involving high power 2D arrays, optical computing, printing, solid-state laser pumps and signal processing. We are presently developing a planar fabrication scheme which will render these devices commercially appealing.

PLZT Thin Films:

Electrooptic and nonlinear optical thin-films, deposited on a variety of substrates including Si and GaAs offer exciting possibilities for integrating the unique capabilities of these materials with semiconductor-based optoelectronics and microelectronics. Novel devices and functionalities will arise from this marriage that will lead to important applications in communications and information processing. PLZT is an attractive material for these studies as a result of its large nonlinear susceptibilities and relative ease of deposition. Other efforts are devoted to a wide range of materials.

PLZT thin-films have been successfully grown by rf-sputtering, multiple-target dc-sputtering and ion-beam deposition. Substrates include fused-silica, Si, thermal SiO_2 on Si, Si, and Al_2O_3. Material qualities are excellent with single peaks in x-ray diffraction measurements indicating highly-oriented growth.

PLZT growth has been extended with the operation and deposition of films using the four-target dc-sputtering system. Films with the correct composition and crystal structure have now been deposited using co-sputtering from Pb, La, Zr, and Ti targets. This is a major milestone towards the exciting capability of fabricating layered PLZT films with enhanced optical characteristics. Three different growth techniques for PLZT films have now been demonstrated at CHTM: single-target rf-sputtering, four-target dc-sputtering, and ion-beam sputtering. Each of these has a unique set of characteristics which affect the film quality and potential uses.

Optical measurements of the PLZT films have continued with a number of major advances. Confocal microscopy has been used, for the first time, to resolve the birefringence associated with individual crystalline grains in the polycrystalline material deposited on fused silica substrate. These measurements have resulted in an upward revision, by a factor of ~ 3, in the electrooptic coefficient of the films. This further enhances the prospects for these materials. Growth of films oriented in the wafer plane is being pursued both by epitaxial growth on crystalline substrates and by growth on patterned substrates. Optical measurements of birefringence and second-harmonic generation in a transverse geometry, with a path length of only 0.5 μm, has continued.

Complex temporal behaviors for long times have been observed. These are due to transport of optically excited carriers under an applied field and can be modelled using the standard Kukhtarev equations from the study of photorefractive phenomena. Detailed modelling is underway.

Using an rf-magnetron sputtering technique and ceramic targets, various ceramic films such as $BaTiO_3$, $LinbO_3$, BBO, SBN, etc. suitable for NLO applications of the thickness ranging from 500 nm up to 2.5 μm have been successfully deposited on various substrates including Si, GaAs, fused SiO_2, and Sapphire. These films have the correct crystal structures and chemical compositions.

Measurements of optical properties of these materials have demonstrated superior behavior. A birefringence contrast ratio of 40 has been demonstrated for a 0.5-μm thick PLT 28/0/100 film. The best film previously reported in the literature had a contrast ratio of only 2. Field-induced second harmonic measurements have shown a contrast ratio of over 900 for similar field strengths. Most important, the response is faster than a nanosecond, which implies that multi-GHz device response will be achievable. A program to develop integrated optical switches using this material has been initiated.

PLZT films have been successfully deposited on Si and SiO_2 substrate with a buffer layer of 2-μm thick of thermally grown SiO_2 film, a usefully monolithical heterogeneous structure for several devices such as UV light detectors. The NLO properties have also been studied in the film, for example, the second harmonic generation has been observed in the film.

Light has been successfully coupled into these films by using three techniques:

Butt coupling,
Prism coupling, and
Grating coupling.

All three techniques provide results showing that light can be guided into the monolithically grown NLO film on semiconducting devices.

PLZT film has been grown successfully on GaAs substrate. Currently, we are studying the chemical interaction between the film and the substrate, and attempts have been made to reduce the interaction by using suitable buffer layer.

Fabrication and Processing

Work has continued on the development of grating fabrication techniques for optical coupling to waveguide modes in integrated optics applications. Careful studies have been made of grating coupling to surface plasmons in metal films and to modes of metal-clad waveguides. Significant polarization selectivities for deep gratings are reported for the first time in the visible spectral range. Preliminary investigations have been made of grating coupling to PLZT films which will be essential for integrated optics applications such as total internal reflection switches. Excellent agreement has been obtained with the experimental results using a reformulated Rayleigh approximation model which is significantly simpler than other approaches available in the literature.

Optical coupling into PLT waveguides has been demonstrated using both butt- and prism-coupling techniques. Estimates of the attenuation length have improved to several μm sufficient for many nonlinear optical and electrooptic applications. These

results are evidence of the high quality of the material produced at CHTM and offer the potential of useful interaction length and electrooptic devices that can operate at low voltages compatible with semiconductor electronics.

We are also developing photolithographic and etching techniques for making the TIR channel waveguide structures for use as high-speed integrated optical switches. A device like this should be operable at a switching speed of 3 GHz, suitable for optical computing and digital signal processing applications.

Device Development

Research in Optoelectronic Device Physics has two main aims: elucidation of basic science to drive long-term R&D efforts, and improvement in understanding of existing materials and devices for rapid development and commercialization of the next generation of optoelectronic systems.

High power semiconductor lasers:

The quest for higher continuous and pulsed power outputs from semiconductor lasers sheds light on semiconductor physics under intense excitation and illumination, and also enables us to reach for new applications. Applications which are especially promising include:

driving other laser sources (e.g. diode-pumped solid-state lasers);
free-space optical communication and fast energy transfer;
illumination, detection and ranging;
probing and processing of technologically important materials.

Semiconductor lasers are easy to drive and extremely efficient, but a major problem is degradation of coherence and stability with increasing power output: above a few tens of milliwatts, spectral broadening and self-pulsations are frequently observed, substantially decreasing the spectral brightness. We have designed, processed and characterized coherent, monolithic, broad-area or multistripe emitters, which were spatially and spectrally filtered using external cavities, maintaining good coherence and stability up to several hundred milliwatts. The latter project has enjoyed significant collaboration with the Semiconductor Laser Technology Branch (AFWL/AROF) at the US Air Force Weapons Laboratory.

We have also studied the physics of hole burning, gain saturation, surface damage, heat sinking, filamentation and other processes which limit laser output power. In each case the goal has been to improve understanding with a view to exploiting or eliminating power-limiting effects and hence develop a new generation of high-power semiconductor lasers. Particular attention has been paid to optimization of pulsed semiconductor lasers for high peak power operation, and we have supplied and characterized several such structures for the Detonation Systems Group (M-7) at Los Alamos National Laboratory.

Coherence and dynamical properties:

Semiconductor lasers have many advantages over other laser sources in commercial and military systems. They are rugged, compact, efficient, reliable, easily driven and modulated. However, they are also relatively noisy and prone to instabilities due to aging or external feedback. We aim to overcome these disadvantages while

maintaining the advantages of these devices, a task which requires careful investigations of basic laser physics.

Reduction in the spectral width of semiconductor lasers is highly desirable for new applications such as coherent optical fiber communication, laser spectroscopy, and certain classes of optical sensors. Improvement in the dynamical properties of these lasers (especially their modulation bandwidths), is required for ultrafast communication and microwave-to-optical conversion. The latter topics are of considerable importance for military and aerospace applications.

We have undertaken fundamental studies of the radiative processes which occur in semiconductor lasers, especially those related to spectral broadening. The all-important linewidth enhancement factor has been measured carefully under typical laser operating conditions. Noise properties and spectral narrowing in free-standing and external-cavity-operated lasers have been investigated theoretically and experimentally. We have conducted basic and applied studies of the transitions to chaos (or optical turbulence), a very interesting condition which gives considerable insight into the dynamics of the laser, and is relevant to spectral narrowing and ultrashort pulse generation. This work has been performed with support from Sandia National Laboratories and in collaboration with the Air Force Weapons Laboratory and Trinity College, Dublin, Ireland.

More applied studies have examined practical line-narrowed laser transmitter geometries, from the points of view of spectral narrowing and stability. Several designs have been devised, analyzed and tested. Device structures, packages and optical interfaces for very narrow linewidth or very high-speed modulation are under consideration.

Optical switching and networking:

Long-distance optical fiber communication systems are now technologically mature: they have enormous information transmission capacities, and are well-suited to high-capacity point-to-point links. However, optical processing (switching, multiplexing/demulti-plexing, filtering, steering, amplification and conditioning) of information is still relatively primitive and inefficient. Hence while long-distance optical telecommunication systems are commonplace, optical exchanges or switches are not yet possible, nor has fiber optics made any significant inroads into local loops or networks.

Similar considerations apply to optical computing. While some specialized analog optical computers are extremely effective, generalized optical computation is still impractical, mostly because of limited availability of optical processing functions and lack of suitable architectures.

The advent of ultrafast, efficient optical switches and logic devices should dramatically improve the prospects for large-scale optical communication and computing. With this in mind, we have studied rapid switching processed in laser diodes, nonlinear etalons and other optical devices. Three projects offer good prospects for success:

- nonlinear waveguide switching and bistability, in which closely coupled twin active optical waveguides allow rapid switching of a beam from one guide to the other under control of an external optical or current pulse;
- polarization switching, in which a control signal may be used to move the output polarization of a laser or filter rapidly between orthogonal states;

• possible two-dimensional parallel switching matrices in resonant periodic gain semiconductor lasers.

These projects have been undertaken with financial support from the USAF Rome Air Development Center and from Sandia National Laboratories.

Assuming that suitable high-speed laser diodes and optical switches can be built to construct an optical network, the next stage of our work is to analyze the global properties of such networks to determine the best configuration for a given application. Once again, data rate and stability are the primary concerns. Extensive previous work on stability and dynamical properties of lasers with external optical feedback have already been applied to this problem, and during 1989-90 we hope to obtain and test several designs for fiber-optical networks, optoelectronic integrated transmitter and receiver circuits, and develop new ways of looking at distributed optical information transmission and processing.

Resonant Periodic Gain (RPG) Structures:

RPGs are novel optoelectronic structures of semiconductor material, envisaged, designed and demonstrated in the CHTM labs over the past two years. Work on the RPG structures was started in early 1987 with emphasis on its application in vertical cavity surface-emitting semiconductor lasers. Surface-emitting lasers have their application in the integrated optoelectronics, optical computing, communications, ultra-high density read/write optical disk drives, printing and 2-dimensional high power laser arrays. However, conventional surface-emitting lasers, both distributed Bragg-reflector grating coupled and vertical cavity DH type, have serious problems associated with their fabrication and short gain lengths leading to high thresholds and low efficiencies. That is why CW operation has only very recently been achieved; such lasers are still not available commercially.

In RPG vertical cavity surface-emitting laser structures most of the problems have been solved by appropriate material engineering which favorably modifies the physical process. In such structures enhanced light-matter interaction doubles the gain-coefficient in the desired direction and suppresses amplified spontaneous-emission which is a major parasitic loss in conventional edge emitters and vertical cavity lasers.

Several RPG structures (GaAs/AlGaAs quantum wells $\lambda/2$ spaced) with integral multi-layer reflectors have been grown at the MOCVD facility of CHTM, which have shown a superb quality. Very low-threshold CW lasing with high quality output beam and efficiencies greater than 45% have been demonstrated under optical excitation. The work on electrical pumping of these structures has also been advanced significantly where processing techniques involving deep diffusion have been developed successfully.

Recently, InGaAs/AlGaAs RPG structures with MLR have been grown on the MOCVD facility and the first room temperature CW lasing with $\eta \geq 43\%$ has been demonstrated with optical excitation. InGaAs QW structures have the advantage that GaAs substrate is transparent at the lasing wavelength which has several applications.

Also very recently, diode-laser pumping of GaAs/AlGaAs RPG has been demonstrated which has shown high efficiency and good mode quality. In fact, this simple arrangement is very promising that at the expense of some power loss but with a very significant improvement in spectral brightness, e.g. power/steradian/nm, a good beam quality can be obtained for coherent communications and various other applications.

Besides integrated MLR-RPG structures, external Fabry Perot and ring cavity experiments with RPG structures are underway. Such investigations would be useful in achieving superb beam quality and properties of RPG as broad area amplifiers. In addition to these technological applications, the fundamental investigation on RPG has resulted in several publications, which has attracted a keen attention of several research groups.

Chirping Effects in Phase-Coupled Laser Arrays:

Conventional phased array lasers with equidistant identical waveguides favor the highest-order supermode that emits a twin-lobe radiation pattern, which is undesirable in most applications. In search of a design that might lead to a stable emission in the fundamental supermode which radiates in a single lobe, we consider chirped arrays with variable waveguide widths and their spacings. Another important element of the design is to allow for excess gain to be present in interspaces, as this alters considerably the order of excitation of supermodes. the relatively poor mode discrimination in large arrays can be remedied by proper gain tailoring, which results in significantly higher gain for the fundamental supermode. Further improvement can be achieved by cutting off the highest-order supermodes, thus reducing mode competition above threshold.

Wavefront Reconstruction in Phased Array Lasers by Lateral Shearing Interferometry:

Many applications of diode laser arrays require stable, nearly diffraction-limited beams. Most existing designs favor excitation of higher-order array modes with broad, twin-lobed far fields. When a single lobe is obtained, it is usually considerable wider than the diffraction limit. The spectrum of array modes present in a beam can be determined by means of wavefront measurements. Phase information is also required to produce single-lobed far-fields using phase-correcting systems. We have proposed and demonstrated a reliable technique for measuring near-field phase fronts by using a laterally sheared ring-type interferometer with zero optical path difference between two beams. This eliminates problems due to equal optical path requirements inn other systems. Fourier transform methods are used to extract phase difference information from the nonuniformly illuminated interferograms, and phase discontinuities between adjacent stripes of carrier-guided laser arrays are observed. Test data agree with theoretical predictions and far-field interpretations.

Coherent Feedback Effects in Short-External-Cavity Semiconductor Lasers

Heterodyne optical communication sources must maintain narrow spectral widths across relatively broad tuning ranges. One of the most promising means of developing such sources is to use external cavities a centimeter or so in length, which may ultimately be integrated monolithically with the laser. Compared to more extensively studied systems with external-cavity lengths of tens of centimeters, short-external-cavity lasers are more stable with respect to mode hopping and intensity noise, and are more tolerant of ambient changes. We have carried out fundamental experimental and theoretical studies of coherent optical feedback effects on the lasing frequency, output power, and mode linewidth of semiconductor lasers. In particular, regions where stable, single-mode operation can be guaranteed have been identified.

Side Mode Injection Locking of Semiconductor Lasers:

Many applications, for example coherent optical communication, require a very stable single-frequency source. Injection locking is a technique that allows to produce such a source by illuminating a slave laser with the light from a well controlled master.

Using multimode rate equations with external optical injection and including the effects of spontaneous emission, we have developed a theory of longitudinal mode selection diode lasers by injection locking. Spectral narrowing and partitioning of power between the free-running and injected modes are considered in detail. The relaxation oscillation frequency is estimated by small-signal analysis of the single-mode rate equations. The relaxation oscillation frequency depends strongly on the choice of target mode, due to the changing differential gain around the gain peak. Modes with shorter wavelengths have faster relaxation oscillations due to their larger differential gain. This phenomenon may be useful in increasing the modulation bandwidth of semiconductor lasers and hence the transmission speed in optical communication systems.

Measurement of Semiconductor Laser Linewidth Enhancement Factor Using Coherent Optical Feedback

The linewidth enhancement factor of a semiconductor laser is defined to be the ratio of the changes in the real and imaginary parts of the complex susceptibility of the laser medium due to carrier density variations. The relation between frequency shift and modal gain change in short-external-cavity semiconductor lasers depends critically on this parameter. A novel method for measuring the linewidth enhancement factor has been devised, in which changes in the optical frequency and external quantum efficiency due to coherent optical feedback are observed. Using this method, the spectral variation of the linewidth enhancement factor was measured for AlGaAs/GaAs channeled-substrate-planar lasers.

Multiple Feedback effects in Asymmetric External Cavity Semiconductor Lasers

Semiconductor lasers are very sensitive to external optical feedback which may affect the optical frequency, linewidth, noise, dynamic behavior and modulation characteristics. A systematic study of multiple-feedback effects on the output power and spectral characteristics of an external-cavity semiconductor laser has been performed. In particular, effects of asymmetric feedback induced by misalignment of an external mirror were included for the first time. The external mirror tile modifies the round-trip phase condition as well as the coupling efficiency. Undulations in power as a function of external-mirror tilt have been observed. We have set up a quasi-static model for asymmetric external-cavity systems which explains qualitatively the observed power undulations with changing tilt angle and complex spectral characteristics.

Diode Laser Arrays in External Cavities with Spatial Filters

Phased array diode lasers are currently of high interest because of their high-power capabilities. One of the major problems is how to design a laser that would emit radiation in a stable, diffraction-limited single lobe instead of the usually observed twin-lobe far-field. Even for lasers designed and fabricated to emit in a single lobe, the radiation patterns often change with output power, under modulation conditions, or with age. A possible solution to these problems may consist in utilizing an external-cavity configuration with spatially selective elements. In our experiments, we used commercial carrier-guided ten-stripe GaAs/AlGaAs laser arrays. The external cavity incorporated a high-reflectivity spherical mirror and a spatial filter formed by an adjustable-width slit. When the slit width was made sufficiently small, a single-lobed, nearly diffraction-limited far field could be maintained at the driving current ranging up to 2.3Ith. The output corresponding power was 205 mW, and 95% of the output was emitted in a narrow beam.

Effective Mass of Holes in InGaAsP Alloys Lattice-Matched to InP:

Rapid growth of the optical communication technology over the past decade is largely due to the development of InGaAsP/InP light sources and detectors. Proper design of such devices largely depends on the detailed knowledge of relevant material characteristics. In spite of intensive studies of InGaAsP alloy semiconductors prompted recently by their practical applications, there remain a number of important material parameters for which only rough estimates are available. Such is the case of the heavy-hole effective mass which is one of the least known parameters even in the case of the binary InP. A critical study of existing theoretical and experimental data for InP reveals an abundance of conflicting results. After establishing which of these data are the most reliable, a new interpolation procedure for quaternary alloys is suggested.

GaAs Surface Degradation Studies:

The reproducibility of photoluminescence intensity is of critical importance to such applications as measurements of surface and bulk recombination times, Surface PL measurements on semiconductors are particularly valuable in characterization of high frequency GaAs integrated circuits in which conduction occurs in a submicron layer near the surface, in optical waveguides formed by surface treatment and in high-power optoelectronic devices where facet conditions are extremely important. Recent experiments with photowashing emphasize the importance of understanding the mechanisms of laser-induced degradation of the surface photoluminescence efficiency in GaAs. We undertook systematic experimental investigations of photoluminescence decay under low-power laser excitation in n-GaAs, p-GaAs and Cr-doped and undoped semi-insulating GaAs. All samples exhibited degradation in photoluminescence efficiency for excitation intensities ranging from 0.1 to 20 kW/cm^2. At least two regimes in rapid photoluminescence degradation were observed for the first time: a fast decay occurring in 1-2 seconds immediately after a surface was freshly cleaved and a relatively slower degradation occurring in several minutes whose rate depended on excitation intensity. On the basis of experimental results, it is suggested that a common physical mechanism related to recombination-enhanced defect migration from the surface is responsible for the observations.

Picosecond Single-Mode Pulse Compression Using 1.3 μm Fabry-Perot Laser Diode and Dispersion-Shifted Fibre

Generation of highly repetitive ultrashort pulses for semiconductor lasers, preferably in a single longitudinal mode, is expected to be very useful in such application areas as multi-gigabit time-division multiplexed (TD) transmission, time-resolved optical sensing like electrooptic sampling, and ultrafast photonic switching. Gain switching is the simplest and most convenient method to produce picosecond pulses without involving any external feedback. We have used this technique to generate the shortest single-mode pulses (FWHM 4.4 ps) of reasonable intensity (0.7 mW) demonstrated so far. This is achieved by separating the oscillating modes of an inexpensive gain-switched multimode 1.3-μm laser with a monochromator and further by compressing the individual pulses in a dispersion-shifted fiber. In addition, feasibility of employing multimode lasers in two schemes for optical fibre transmission, namely TDM and hybrid TDM/WDM (wavelength division multiplexing),, has been demonstrated. both schemes have the additional appeal of exploiting most of the output power of the laser.

Journal Publications

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